

Time-Resolved Research at the Advanced Photon Source Beamline 7-ID

Eric M. Dufresne*, Bernhard Adams*, Dohn A. Arms*, Matthieu Chollet*, Eric C. Landahl†, Yuelin Li*, Donald A. Walko* and Jin Wang*

**X-ray Science Division, Argonne National Lab., Argonne, IL 60439, USA*

†Department of Physics, DePaul University, Chicago IL 60614, USA

Abstract.

The Sector 7 undulator beamline (7-ID) of the Advanced Photon Source (APS) is dedicated to time-resolved x-ray research and is capable of ultrafast measurements on the order of 100 ps. Beamline 7-ID has a laser laboratory featuring a Ti:Sapphire system (average power of 2.5 W, pulse duration <50 fs, repetition rate 1-5 kHz) that can be synchronized to the bunch pattern of the storage ring. The laser is deliverable to x-ray enclosures, which contain diffractometers, as well as motorized optical tables for table-top experiments. Beamline 7-ID has a single APS Undulator A and uses a diamond (111) double-crystal monochromator, providing good energy resolution over a range of 6-24 keV. Available optics include Kirkpatrick-Baez (KB) mirrors to microfocus the x-ray beam. A variety of time-resolved diffraction and spectroscopy research is available at 7-ID, with experiments being done in the atomic, molecular, optical, chemistry, and solid state (bulk and surface) fields.

Keywords: Ultrafast lasers, pump-probe experiments, time-resolved diffraction and spectroscopy

PACS: 61.10.-i, 61.80.Ba, 61.72.Dd, 65.40.De

INTRODUCTION

The 7-ID beamline of the Advanced Photon Source is dedicated to time-resolved x-ray research. This unique beamline combines a multi-GW femtosecond laser with dedicated stations for time-resolved x-ray diffraction, spectroscopy, unfiltered white beam, and microfocus techniques. This paper describes briefly the facilities available for APS general users.

X-RAY SOURCE AND 7-ID-A HUTCH OPTICS

The Sector 7 insertion device (ID) beamline has three special characteristics. The first is that the hutches are very large by comparison to most other sectors at the APS, as well as to other synchrotron sources worldwide. This has permitted the concurrent development of several different x-ray techniques at the same sector, all of which are used in the time-resolved research program (see Fig. 1). It has also allowed the construction of complicated experiments, such as the x-ray microprobe of gases in a strong laser field [1, 2]. The second characteristic is the availability of a white-beam enclosure (7-ID-B). Such heavily shielded hutches are rare on undulator beamlines at the APS, and they permit the full average power (exceeding 1 kW) of the undulator source to be delivered to an experiment, such as time-resolved phase-contrast imaging of thick objects [3]. The third characteristic is a femtosecond laser system, located in a laser laboratory immediately adjoining the end of the sector. Many specialized instruments for time-resolved x-ray studies (e.g., fast photodiodes, x-ray streak cameras, and gating electronics) are available.

The 7-ID x-ray source is an APS Undulator A (UA). It has a fundamental tuning range from 3 to 13.5 keV, a period of 3.3 cm, and a length of 2.4 meters. The calculated UA energy spectrum when set at 10 keV contains approximately 4×10^{15} photons per second in the fundamental.

The 7-ID-A enclosure contains a polished 0.508-mm-thick Be window, placed about 25.5 m from the source (APS W2-82 window assembly). This window and mask in the 7-ID front end limits the white beam generated by an APS Undulator A to an area of 3 mm (H) by 2 mm (V). This limits the power down the beamline to about 1 kW. A white-beam slit placed 26.5 m from the source (APS L5-20 slit) enables one to reduce the size of the white beam on the downstream optics. A Kohzu HLD-4 high-heat-load monochromator follows the slit. This water-cooled double-crystal

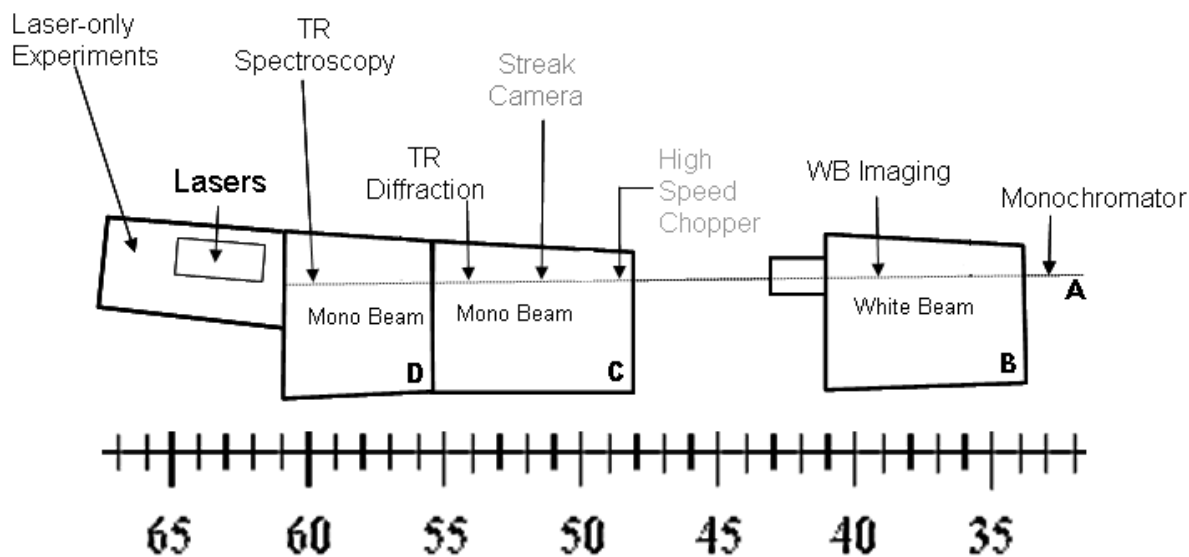


FIGURE 1. The Sector 7 beamline layout. WB stands for white beam; TR for time-resolved capability. Instruments shown in gray are undergoing commissioning in 2009.

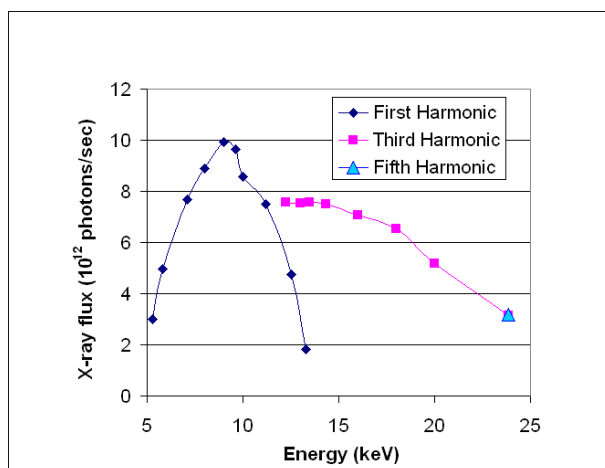


FIGURE 2. The measured flux of the monochromatic beam on 7-ID under typical experimental conditions.

diamond (111) monochromator was installed in June 2006. Its nominal energy range is 5 to 24 keV with the measured flux, under normal operating conditions, shown in Fig. 2.

Figure 3 shows the measured energy bandpass of this monochromator. It was measured with Si (555) at 9.887 keV. The back-reflected signal from the single crystal was measured with an ion chamber on top of the background from the incident beam. Its measured energy bandpass full-width at half maximum is $\Delta E/E = 5.4 \times 10^{-5}$. A mode shutter (APS P4-20) ends the 7-ID-A station and allows either the monochromatic beam or the white beam to pass.

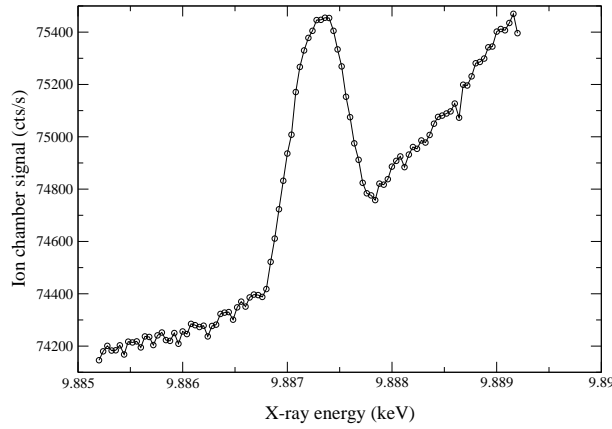


FIGURE 3. The measured bandpass of the monochromatic beam on 7-ID.

EXPERIMENTAL STATIONS

The laser system is housed in a separate, non-x-ray 7-ID-E enclosure and can be sent to the 7-ID-C and 7-ID-D hutches through laser labyrinths. Tabletop experiments can also be performed on a breadboard upstream of the diffractometer. Electronic gating of the x-ray detector output (typically an avalanche photodiode) allows for the simultaneous recording of laser on / laser off x-ray data. Delays between the laser and x-ray pulses are generated entirely electronically, with the use of computer-controlled phase shifters so that delays from 0.5 ps to 1 ms can be achieved without the use of optical delay lines [4]. Analog phase shifters can be used for rapid-delay scanning within a few ns. A Huber 6-circle Psi diffractometer at the rear of 7-ID-C is available for static and temperature-dependent measurements, and now hosts most of the time-resolved diffraction experiments at the sector [5, 6, 7]. A Dysplex cryostat is available for cooling the sample down to 10 K. It has a clear plastic dome that transmits 800 nm light as well as 10 keV x-rays.

A laser-triggered x-ray-sensitive streak camera is available in 7-ID-C for experiments that operate on time scales shorter than the x-ray bunch length (about 100 ps). This camera resides in 7-ID-C on a large motorized optical table. Experiments must be performed with x-rays nearly parallel to the incident beam. A vertical-bounce-double-crystal setup is under development for single-crystal diffraction experiments. The camera has a 1.6 ps resolution to a UV short pulse, and activities are ongoing to bring its resolution below 1 ps.

The 7-ID-B hutch hosts a variety of experiments and is especially well suited for white-beam and pink-beam imaging experiments [3]. At the front and back of the hutch, water-cooled 0.508-mm-thick Be window assemblies allow the white beam into and out of the hutch. The white beam is stopped in a small mini-hutch placed downstream of 7-ID-B housing a P5-20 white-beam stop and monochromatic shutter system.

A time-resolved microprobe of intense laser fields has been developed by Argonne's Atomic Physics Group. A Kirkpatrick-Baez mirror pair focuses the x-ray beam to a measured spot size about $6\text{ }\mu\text{m}$ by $7\text{ }\mu\text{m}$ inside a vacuum chamber. A charge-coupled device (CCD) camera views the laser and x-ray focal spots on a fluorescent BGO screen, and crosshairs or knife-edge scans are used to precisely overlap the two beams. Fluorescence spectroscopy of atomic and molecular gases during ionization, dissociation, alignment, and laser-field dressing are measured using various detectors that can be gated to the laser-coincident x-ray pulses [1, 2, 8].

LASER LABORATORY

The laser system is a standard kHz Ti:Sapphire amplified system. The oscillator is a Coherent Micra with a nominal average power of 300 mW, a maximum bandwidth of 100 nm, a pulse duration of 20 fs, and an 87.98 MHz repetition rate. It is designed to be synchronized to the accelerator rf within 250 fs rms. This new oscillator was installed in 2008, and replaced a KM-Lab Ti:Sapphire oscillator that was pumped by a Coherent Verdi (5 W) [1]. The chirp-pulsed amplification (CPA) laser amplifier is pumped by a 30 W diode-pumped Nd:YLF (Coherent Evolution 30). The 800-nm Ti:Sapphire CPA regenerative amplifier (Coherent Legend) delivers 2.5 W of average power compressed to 50-60

fs.

Pulse energies of 2.5 mJ/pulse at 1 kHz or 0.5 mJ/pulse at 5 kHz are possible, as well as conversion to higher harmonics using non-linear crystals. Extra space in the new laser lab allows for off-line laser-only setup of experiments such as streak camera development, time-of-flight detector tests, and coherent phonon detection. The essential parameters of the laser and beam delivery optics can be controlled remotely via a computer interface.

UPGRADES UNDERWAY

Upgrades of the laser system to commercial products over the past five years have improved the laser reliability and stability. In the past year, many EPICS-based laser controls were implemented to help with routine operation of the laser. We are designing vacuum beam transport tubes and relay imaging techniques to improve the laser beam stability.

The use of a Pilatus pixel-array detector for data collection has been found to vastly improve the data collection efficiency. The Pilatus can be gated to match the 24-bunch mode of the APS [9]. It has already been shown to speed up the data-collection rate for surface diffraction by an order of magnitude.

We are currently procuring a new KB mirror system with 320 mm long flat that will enhance the focused flux for spectroscopy experiments. The clear optical length of this system is 280 mm, so the improvement in usable beam cross section may be up to a factor of $(280/172)^2 = 2.65$. The bender mechanism should also provide improved control.

An exhaust system was also recently installed for each experimental hutch. These allow the study of hazardous gases excited by the laser. A dedicated white-beam imaging setup is also being installed in 7-ID-B.

Recent results from the facility include the study of photo dissociation of Bromine with ultrafast UV pulses with EXAFS [10], and the x-ray near-edge study of laser-aligned CF_3Br [2]. It is possible to measure the pulse duration of the APS with a recently developed laser-x-ray cross-correlation technique [8].

Several new laser-pump, x-ray probe measurements have been published such as the observation of unfolded acoustical phonons in an InGaAs/InAlAs superlattice [6] or the measurement of the thermal conductivity of a buried interface of an $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As/GaAs}$ heterostructure [7]. The facility welcomes APS General Users.

ACKNOWLEDGMENTS

Use of the Advanced Photon Source was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

REFERENCES

1. S. Southworth, D. Arms, E. Dufresne, R. Dunford, D. Ederer, C. Höhr, E. Kanter, B. Kraessig, E. Landahl, E. Peterson, J. Rudati, R. Santra, D. Walko, and L. Young, *Physical Review A* **76**, 043421 (2007).
2. E. Peterson, C. Buth, D. A. Arms, R. Dunford, E. Kanter, B. Kraessig, E. C. Landahl, S. Pratt, R. Santra, S. Southworth, and L. Young, *Appl. Phys. Lett.* **92**, 094106 (2008).
3. K.-S. Im, K. Fezzaa, Y. Wang, X. Liu, and J. Wang, *Appl. Phys. Lett.* **90**, 091919 (2007).
4. D. Reis, M. DeCamp, P. Bucksbaum, R. Clarke, E. Dufresne, M. Hertlein, R. Merlin, R. Falcone, H. Kapteyn, M. Murnane, J. Larsson, T. Missalla, and J. Wark, *Phys. Rev. Lett.* **86**, 3072 (2001).
5. M. Highland, B. C. Gundrum, Y. K. Koh, R. S. Averback, D. G. Cahill, V. C. Elarde, J. J. Coleman, D. A. Walko, and E. C. Landahl, *Phys. Rev. B* **76**, 075337 (2007).
6. M. Trigo, Y. M. Sheu, D. A. Arms, J. Chen, S. Ghimire, R. S. Goldman, E. Landahl, R. Merlin, E. Peterson, M. Reason, and D. A. Reis, *Physical Review Letters* **101**, 025505 (2008), URL <http://link.aps.org/abstract/PRL/v101/e025505>.
7. Y. Sheu, S. Lee, J. Wahlstrand, D. Walko, E. Landahl, D. Arms, M. Reason, R. Goldman, and D. Reis, *Phys. Rev. B* **78**, 045317 (2008).
8. B. Krässig, R. W. Dunford, E. P. Kanter, E. C. Landahl, S. H. Southworth, and L. Young, *Appl. Phys. Lett.* **94**, 171113 (2009).
9. T. Ejdrup, H. T. Lemke, K. Haldrup, T. N. Nielsen, D. A. Arms, D. A. Walko, A. Miceli, E. C. Landahl, E. M. Dufresne, and M. M. Nielsen, *J. Synch. Rad.* **16**, 387–390 (2009).
10. C. G. Elles, I. A. Shkrob, R. A. Crowell, D. A. Arms, and E. C. Landahl, *J. Chem. Phys.* **128**, 061102–1 to 061102–4 (2008).